Tevatron 2014 Impact on the NOνA Experiment

ABSTRACT

The recently proposed extension of the Tevatron run into 2014 would:

- Reduce the NOνA $\nu_\mu \rightarrow \nu_e$ data set by roughly a factor of 2 during the 2015 – 2016 time period
- Delay first results on muon antineutrino oscillations by 2 years
- Delay first results on the mass ordering and the CP violating phase by 2 years
- Delay final results by 1.5 years
- Add an additional 3.7M$ to the cost of the project.

Introduction

The primary goal of the NOνA experiment is to measure the parameters of $\nu_\mu \rightarrow \nu_e$ oscillations. There are three standard model parameters that are largely or completely unknown: θ_{13}, for which there are upper limits and global fits hinting at a small non-zero value; the CP violating phase δ, which is completely unknown; and the mass ordering of the doublet of mass states responsible for solar neutrino oscillations with respect to the third mass state. Although the primary interest of the NOνA experiment will be in gaining information on the latter two parameters, a necessary precondition is the observation of $\nu_\mu \rightarrow \nu_e$ oscillations, and the magnitude of these oscillations is largely proportional to the value of $\sin^2(2\theta_{13})$. Thus, sensitivity to $\sin^2(2\theta_{13})$ is a useful gauge to compare the sensitivity of the various second generation experiments. Should $\sin^2(2\theta_{13})$ prove large enough, the NOνA long baseline and planned antineutrino running put it in the unique position to study the mass ordering and CP violating phase.

Three reactor experiments will be reporting data in the coming few years: Double Chooz, RENO, and Daya Bay. These experiments are only sensitive to $\sin^2(2\theta_{13})$. The other second generation long-baseline neutrino oscillation experiment is T2K. It will have sensitivity to δ (if it runs antineutrinos), but will have essentially no sensitivity to the mass ordering due to its relatively short baseline. The rate of $\nu_\mu \rightarrow \nu_e$ oscillations is sensitive to all three parameters and also to $\sin^2(\theta_{23})$, which has a present uncertainty of about ±25%. Thus, an "effective $\sin^2(\theta_{13})$", measured using accelerator experiments can vary by as much as a factor of 2.5 from that measured by reactor experiments. A difference in the measurement of the rate of $\nu_\mu \rightarrow \nu_e$ oscillations between T2K and NOνA is in principle due to matter effects, which are used to determine the mass ordering. Thus, there will be a competition between all these experiments to present data on these unknown parameters, but also a large degree of complementarity in the results.

If the value of $\sin^2(\theta_{13})$ is small, then all of these experiments will play an important role during the 2014-15 time frame in determining whether it is sensible to proceed with the LBNE project. Although, the NOνA experiment is starting later than the other experiments, it will be competitive in this time frame, as will be discussed below. This competitiveness has recently been enhanced by advances in the NOνA schedule.

A secondary goal of the NOνA experiment is the precise determination of the dominant neutrino oscillation parameters $\sin^2(2\theta_{23})$ and Δm_{23}^2, for both neutrinos and antineutrinos. If the ~2σ difference between neutrinos and antineutrinos recently reported by the MINOS experiment persists, it will be measured by NOνA at 4σ significance with one year of antineutrino running.

In the following, we lay out the present NOνA schedule and the impact on the NOνA project and experiment by an extension of the Tevatron running, and then discuss the consequences.

Scenarios

Baseline Scenario

Our present plans, which, for convenience, we will call the "Baseline Scenario," are as follows: An 11 month shutdown will start in March 2012 during which the NOνA Near Detector Cavern will be excavated, the target area will be converted to the medium energy configuration, and the necessary work to convert the Main Injector and the Recycler to the 700 kW capacity will completed. The construction of the NOνA Far Detector will continue through this period with approximately half of the detector ready to take data at the conclusion of the shutdown.

After the shutdown, we assume that a six-month commissioning of the accelerator complex will take place with a linear increase in beam intensity. The full far detector will be ready to take data in September 2013, shortly after the completion of the accelerator commissioning. For the purpose of these calculations, we assume a 15 kt far detector, 1 kt more than our CD-4 requirement. Our present contingency projections allow this increase, and there is the possibility of using earned contingency to add additional detector mass beyond 15 kt.

We will run for a full standard NOνA year (15 kt detector mass and 6×10^{20} protons on target (POT) delivered to NuMI = 90×10^{20} kt-POT) in neutrino mode before considering a switch to antineutrino running. The decision to start the antineutrino run will depend on the value of $\sin^2(2\theta_{13})$ and what is known from other experiments at the time. Thus, the earliest time we would consider a switch to antineutrinos would be about June 2014.

Impacted Scenario

We make the following assumptions to estimate the performance of the NuMI beam should the Tevatron run be extended through FY 2014.

- Use of the NOνA/ANU design values for accelerator capabilities. The Run IIc proposal assumes a higher power to the NOνA target but the accelerator performance required for this has not been demonstrated and there is no defined path to reach this performance. Using the NOνA/ANU assumptions on accelerator performance result in an estimated 396 kW of beam power in the impacted scenario and 706 kW in the baseline scenario. These assumptions allow a consistent comparison of the two scenarios.

- A short shutdown (2-3 months) will occur near the start of Run IIc (nominally March 2012) to install some of the ANU Main Injector upgrades to achieve a 1.333 s base cycle for the Main Injector. In addition to normal maintenance, these installations include a quadrupole bus power supply and two Main Injector 53 MHz RF cavities (bringing the total to 20). Including the fill time, the cycle is then 2 s.
- The cycles are interleaved as in the Run IIc proposal, such that NOνA receives 11 Booster batches half of the time, and 9 Booster bunches the other half of the time.

We then make comparisons between the beam powers in the two scenarios. The details are in Table 1; the primary result is that beam power is degraded from approximately 700 kW to 400 kW, a 44% reduction. This can be compared to the 320 kW presently available for NuMI.

	Baseline	Run IIc
Booster batch Intensity (e12)	4.3	4.3
Average number of NOνA batches	12	10
MI efficiency	0.95	0.95
Average NOνA Intensity (e12)	49	41
Fill period (s)	0	0.67
Base cycle time (s)	1.33	1.33
Total cycle time (s)	1.33	2.00
NOνA Power (kW)	706	392

Table 1. Beam parameters for the baseline scenario and impacted scenario during Run IIc.

The reduction from 700 kW to 400 kW comes from two factors: The average number of batches is decreased from 12 to 10 (50% @ 9, 50% @ 11), reducing the average intensity from 49×10^{12} to 41×10^{12}, and the total cycle time is increased from 1.33 s to 2.00 s.

In parallel with the short Main Injector shutdown mentioned above, we assume an 8-month NuMI shutdown to excavate the Near Detector Cavern and to install the medium energy target and horns. At the end of this shutdown in December 2012, we assume that the NuMI beam will come on at 400 kW with negligible commissioning time, since no major changes have been made to the accelerator complex.

In October 2014, we assume an additional 8-month shutdown to make the modifications to the Main Injector and the Recycler for 700 kW operation. As in the baseline scenario, we assume that a six-month commissioning of the accelerator complex will take place with a linear increase in beam intensity, with full intensity available around December 2015.

These two scenarios are summarized in Fig. 1. Figure 2 shows the cumulative POT and the construction of the far detector as a function of time for the two scenarios, plus an additional scenario in which the conversion to 700 kW is omitted and a 9% increase in protons to NuMI is realized with the end of the Tevatron program. This last scenario is clearly not optimum and will not be discussed further.

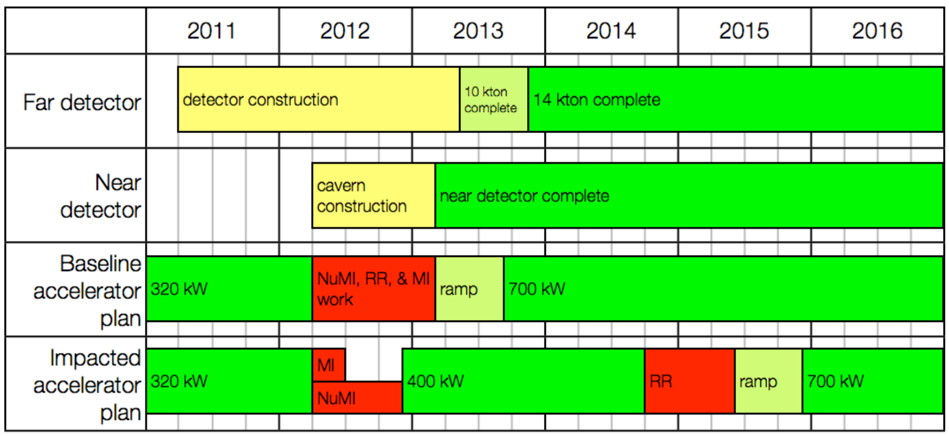

Figure 1. Summary of the NOvA detector construction and the two operations scenarios. In the operations scenarios, red blocks are shutdowns, green blocks are production running, and yellow blocks are accelerator commissioning assuming a linear intensity ramp.

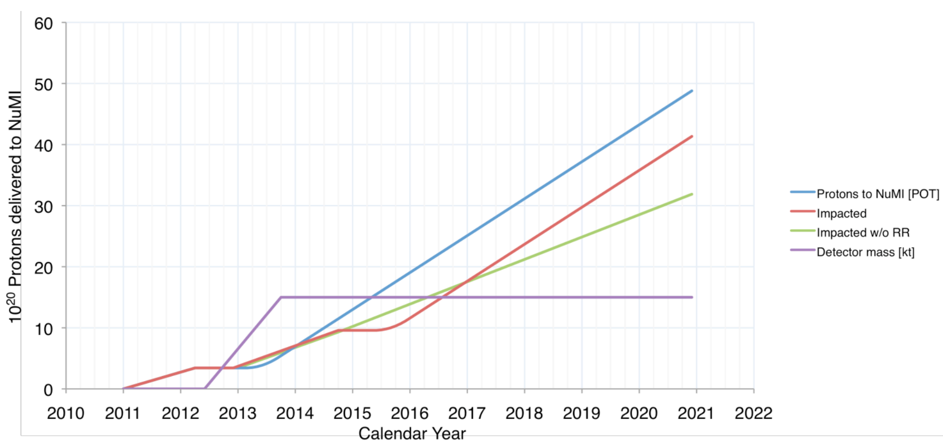

Figure 2. Integrated pot in the baseline (blue), impacted (red) and impacted without going to 700 kW (green) as a function of time. The Far Detector construction is also show (purple) in units of kt.

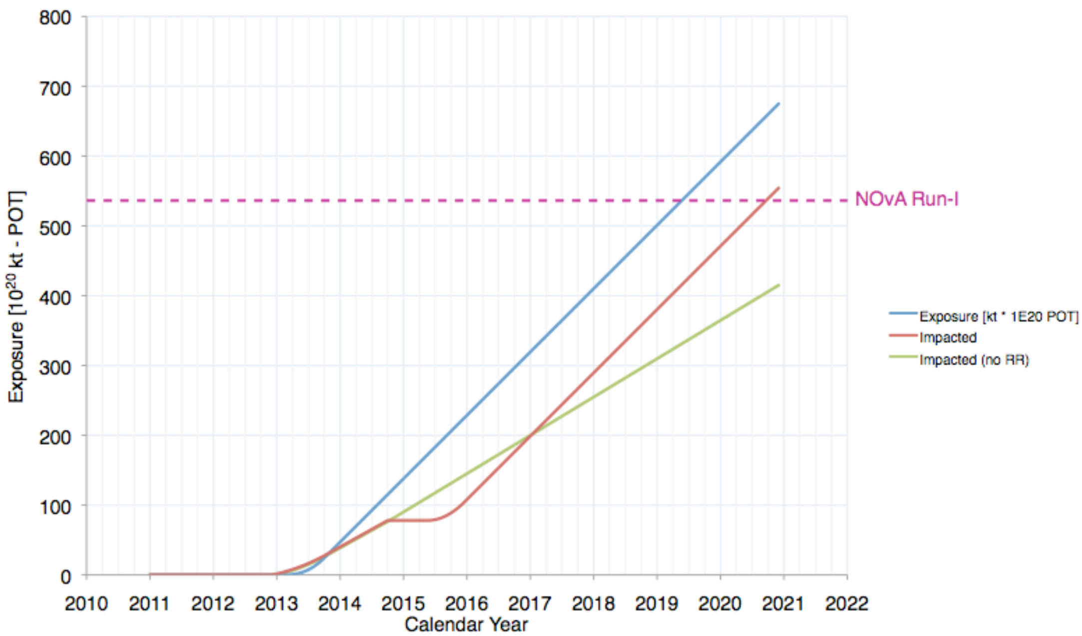

Figure 3. Cumulative product of Far Detector mass times pot as a function of time. The proposed NOνA run is for 560 kT-10^{20} pot, shown by the dashed horizontal line. The scenarios are as in Fig. 2.

Discussion

Figure 3 shows the cumulative product of detector mass and POT. A nominal NOνA year is 90 kt-10^{20} POT. NOνA was proposed to run 6 years for a nominal product of 540 kt-10^{20} POT, shown by the horizontal dotted line. The overall impact is a delay of one and a half years of running. The proposed run would end in July 2019 in the baseline scenario and in January 2021 in the impacted scenario.

However, the impact at 2019 is of less import than that in the 2014-2015 period when all of the experiments will have significant results. Figure 4 shows the ratio of the product of cumulative detector mass times pot for the impacted scenario to the baseline scenario. The ratio is around or less than 0.5 during the crucial 2014-2015 period when the impact, by this measure, is largest.

NOνA should be quite competitive in the 2014 – 2015 time frame. We have estimated the 90% confidence level sensitivity to $\sin^2(2\theta_{13})$ (or the effective value for accelerator experiments assuming a normal mass ordering and $\delta = 0$) at the end of 2014. These values are shown in Table 2. The T2K values come from integrating the red curve shown in Figure 5. This figure comes from the February 2010 J-PARC PAC meeting.[1] (Warning: These sensitivities are calculated using Gaussian statistics and are useful for comparisons. However, if $\sin^2(2\theta_{13})$ is small, in the 0.01 to 0.02 range, then both NOνA and T2K will only have a handful of events in this time frame requiring the use of Poisson statistics.)

[1] http://gpppc6.lps.umontreal.ca/azuelos/Seminaires/current/T2K-status-Feb2010.pdf

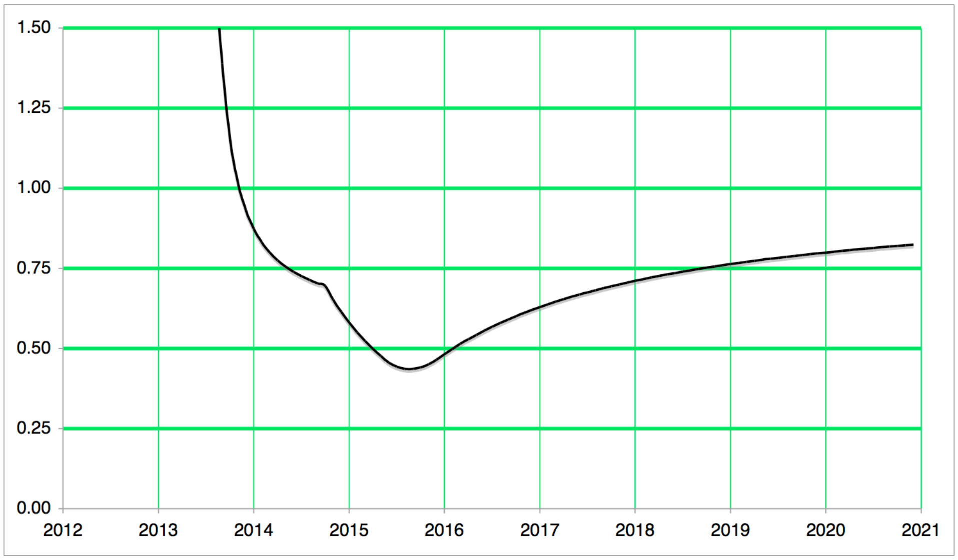

Figure 4. The ratio of the product of cumulative detector mass times pot for the impacted scenario divided by the baseline scenario as a function of calendar year. The largest impact occurs in mid 2015.

Experiment	**Sensitivity**
Double Chooz	0.03
RENO	0.02
Daya Bay	0.009
T2K	0.02
NOνA baseline	0.011
NOνA impacted	0.015

Table 2. Estimated sensitivities at the 90% confidence level for $\sin^2(2\theta_{13})$ at the end of CY 2014.

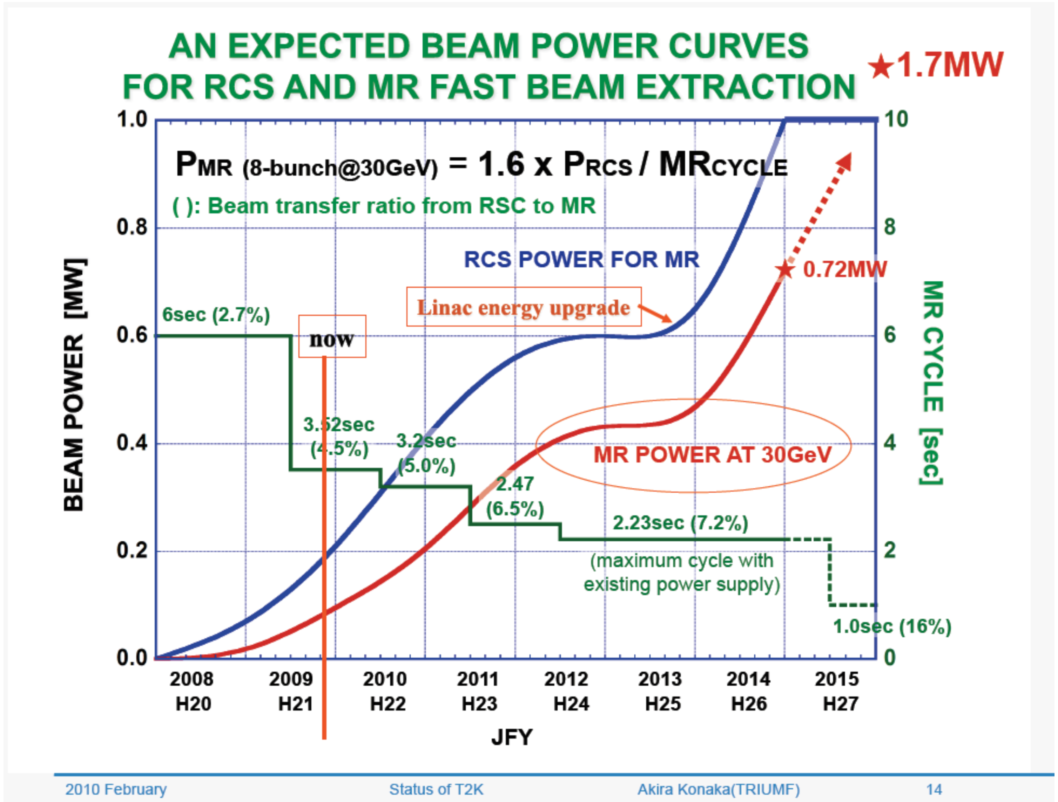

Figure 5. Expected T2K beam power as a function of time.

Another consideration for NOνA is antineutrino running. Information on both δ and the mass ordering is derived from a comparison of neutrino and antineutrino oscillation rates. Further, antineutrino running will be used to search for non-standard interactions and to check the discrepancy that MINOS presently observes, if it persists to that time. If $\sin^2(2\theta_{13})$ is sufficiently large, then NOνA will probably start antineutrino running after it has accumulated a full standard NOνA year of neutrino data, but not during accelerator commissioning, since it will want to verify that previous neutrino rates are being observed. Under these assumptions, the periods of neutrino and antineutrino running are shown in Fig. 6. The impacted scenario would delay antineutrino running until mid 2016, a delay of two years.

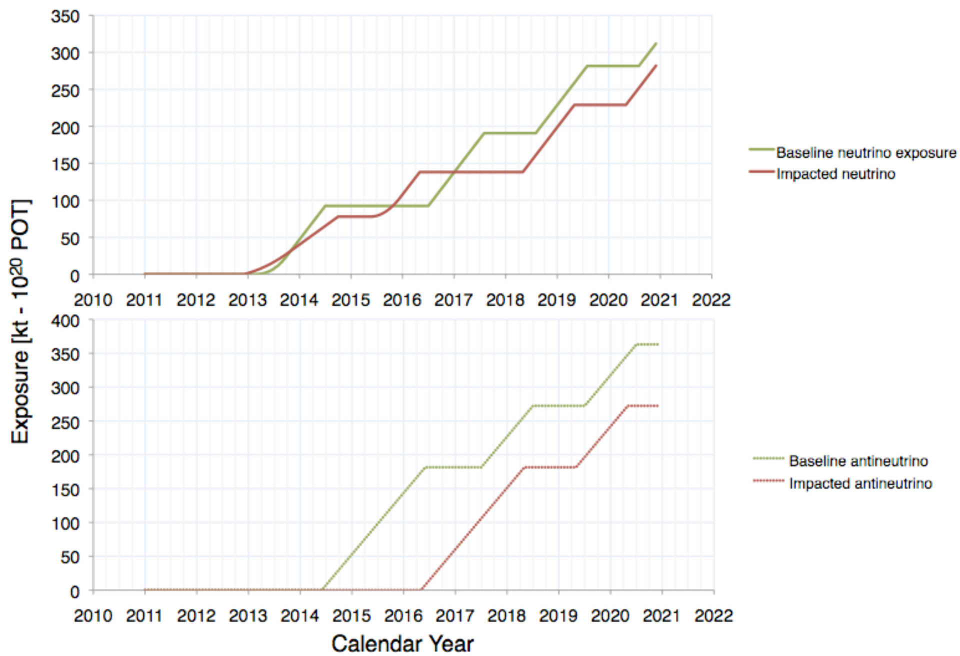

Figure 6. Periods of expected NOνA neutrino and antineutrino running.

Project cost and schedule

The impacted scenario delays the NOνA project CD-4 milestone by at least 1 year. Moving this milestone requires the approval of the Director of the DOE Office of Science and the DOE Deputy Secretary. This delay would have a cost of about 3.7M$, 1.1M$ from escalation on the delayed modifications to the Main Injector and Recycler and 2.6M$ from continuing (but reduced) project management.

Summary

The proposed Tevatron extension would make its largest impact on the NOνA experiment during the years 2015 - 2016 when the experiment would have half the data available for its first results than it would otherwise have. The extension would delay running of antineutrinos by about 2 years, delaying first results on muon antineutrino oscillations, mass ordering, and the CP violating phase δ by that amount. The final NOνA results would be delayed by 1.5 years. The delay in the project would require moving milestones held at high levels in the DOE and incur additional costs of approximately 3.7$M.